ECE 345 / ME 380: Introduction to Control Systems
Collaborative Quiz #2

Dr. Oishi

Due Thursday, September 22, 2020 at the end of class

Researchers have recently developed a human-machine interface for a soft robot, a lens that "mimics the working mechanisms of the eyes of humans and most mammals" [1]. The lens is constructed of a responsive polymer, which can act like an artificial muscle, similar to the muscles around your eye. By measuring electric pulses associated with eye movement, the automated soft lens direct the lens to focus on different areas according to the user's gaze.

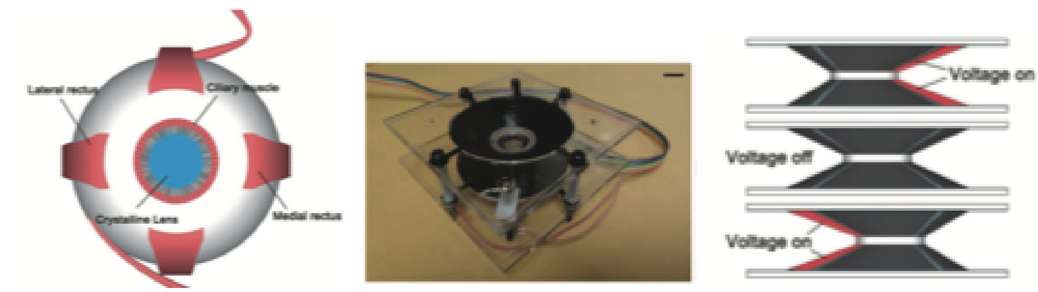


Figure 1: Biomimetic soft lens that is controlled by the user's eye movement. By applying an electric potential to the polymer surrounding the lens, the material shrinks or expands, refocusing the lens. [1]

Such a system could be a prototype for a visual prosthesis, adjustable glasses, or remotely operated robotics, for example.

> *...there may be a day — in the not so distant future — when our glasses and contact lenses can read and respond to these eye movements, adjusting in real time to the electrical signals created by the muscles in the lens.*
>
> *Inventions like "adjustable glasses" could follow, unleashing a new era of eyewear that would either organically adjust to someone's eye movements or allow wearers to control a lens by blinking...* (from `https://tinyurl.com/y5ndnw3m` [2])

In this exercise, we will consider the design of a soft lens system, modeled via the transfer function

$$G(s) = \frac{2500}{s^2 + Ks + 2500} \tag{1}$$

The input $u(t)$ is the desired location for the lens to focus on. The output $y(t)$ is the actual position of the lens. We wish to design the parameter K to achieve a fast response that does not cause excessive overshoot; specifically, with overshoot less than or equal to 5% and settling time less than or equal to 1.6 seconds. A secondary criteria for the system is that the peak time is less than $\pi/5$ seconds. We presume that K is strictly positive, i.e., $K > 0$. *The goal of this exercise is to analyze the transient response of the lens system, and to evaluate its performance.*

1 Questions to be completed before class

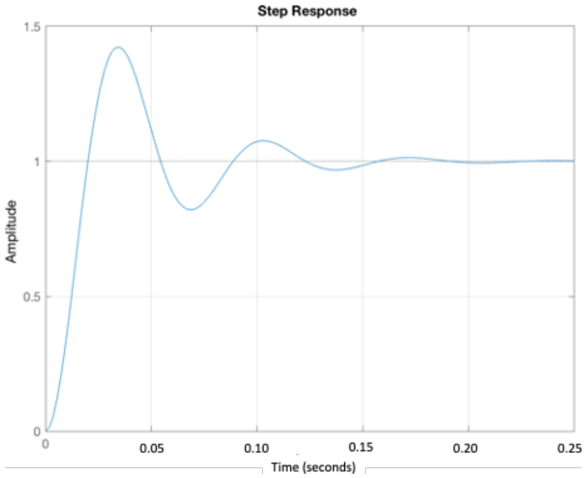
Complete the following in preparation for the work to be done during class. *Your answers to these questions do not need to be handed in.*

1. Find the poles and the zeros of the system, and the characteristic equation.
2. Show that the state-space representation of (1) in phase variable form has state matrix $A = \begin{bmatrix} 0 & 1 \\ -2500 & -K \end{bmatrix}$.
3. Find the damping ratio, ζ, and the natural frequency, ω_n, for the system (1). *Hint: You should obtain a damping ratio that is dependent on K, and a natural frequency that is not dependent on K.*
4. Calculate the settling time, T_s, and the peak time, T_p, in terms of the parameter K.

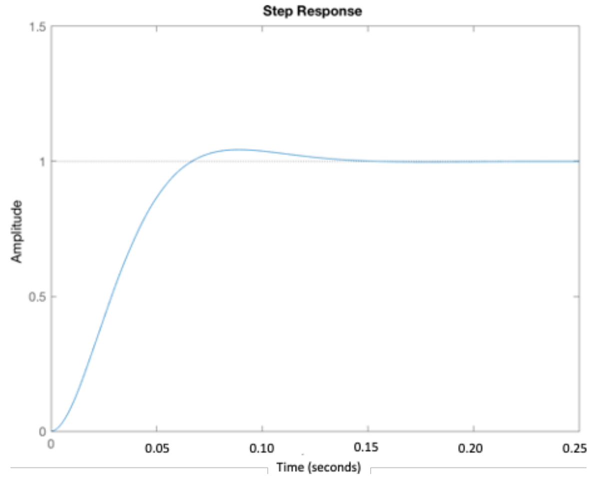
2 Questions to be completed in class, in groups

Transcribe your answers to the following to your group's answer sheet, to be handed in.

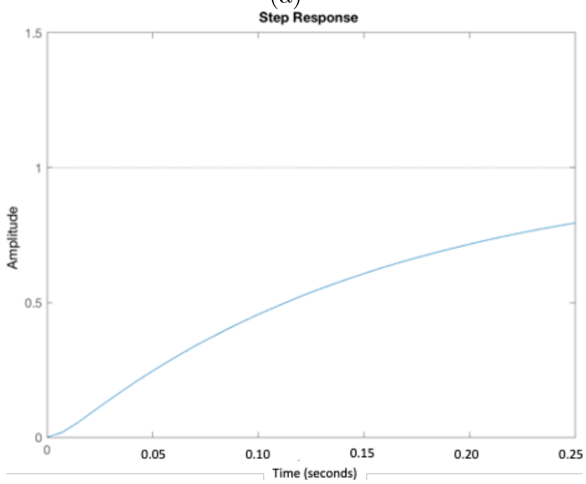
1. Compare your responses to Pre-Class Questions #1 and #2. Which of the following statements are correct? *More than one answer may be selected.*
   (a) The eigenvalues of A are the same as the roots of the characteristic equation.
   (b) The poles of $G(s)$ are the same as the eigenvalues of A.
   (c) The characteristic equation is described by the equation $|sI - A| = 0$.
   (d) The zeros of $G(s)$ are the same as the eigenvalues of A.
2. Consider the design specifications above for settling time and overshoot. Which of the following step responses satisfies those specifications? *More than one answer may be correct.*



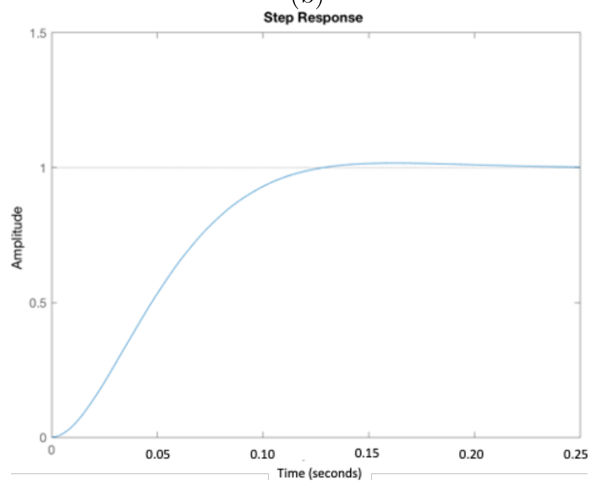
(a)



(b)



(c)



(d)

3. Use your answer to Pre-Class Question #3 to label the lines (or curves, as appropriate) on the plot on the grading sheet, that depict

   (a) Damping ratio $\zeta = 1/\sqrt{2}$

   (b) Natural frequency $\omega_n = 50$

   (c) Settling time $T_s = 0.16$ seconds

   (d) Peak time $T_p = \pi/50 \approx 0.06$ seconds

4. Consider your answer to Pre-Class Question #4. Which of the following most correctly describes the effect of K on settling time for $G(s)$?

   (a) As K increases, settling time decreases.

   (b) As K increases, settling time increases.

   (c) Settling time is inversely proportional to K.

   (d) Settling time is not dependent upon K.

5. Consider two possible control gains: $K = 50\sqrt{2}$ or $K = 40$. Evaluate the design specification for these gains. Which of these gains provides the most suitable response? Briefly justify your response in a sentence or two.

References

[1] J. Li, Y. Wang, L. Liu, S. Xu, Y. Liu, J. Leng, and S. Cai, "A biomimetic soft lens controlled by electrooculographic signal," *Advanced functional materials*, vol. 29, no. 36, p. 1903762, 2019.

[2] P. Holley, "Researchers just created a robotic lens that can be controlled by the eyes," *The Washington Post*, August 15 2019.